Plasma Etching /Plasma Spray Coatings /Plasma Processing/Plasma Electronics/Ion Implantation/ Surface Cleaning/Toxic Waste Destruction/Remote Maintenance/Isotope Separation/X-Ray and Ultraviolet Lithography / Diamond Films/Organic Coatings/High Power Microwaves/Instrumentation /Prosthetics and Implants/ Micromachining/ Anti-Corrosion Coatings / Surface Hardening /High Performance Ceramics/New Alloys/ Superconductors/Ultraviolet Drying /Plasma Light Source/Hand-held Radar/ Laser Surgery /Cryogenics/ Tissue Welding/Medical Imaging/Biodegradable Packaging/Supercomputer Networks /Precise Machining/ Polymer Films for Recording

INVESTMENT IN AN ENERGY SOURCE FOR TOMORROW

FUSION

YIELDS IMPORTANT BENEFITS TODAY

BENEFITS TODAY

Research funded by the U.S. Department of Energy to develop fusion — the energy process of the Sun and other stars — has spawned a new branch of physics — plasma physics — and has resulted in the invention of technologies to produce and manipulate plasma for many purposes.

Products manufactured using plasma science and technology impact our daily lives in many significant ways.

PLASMA PROCESSING OF CHIPS AND CIRCUITS

Small, fast computer chips (such as the Pentium™ chip) and associated miniature integrated circuits have led to a revolution in the personal computer industry. Approximately 40% of the steps required to produce such chips and circuits use plasma processing.

COATINGS OF MATERIALS

Polymer films for recording media, and longer-lasting products ranging from machine tools to medical implants, result from coatings placed on materials by such technologies as plasma spray and sputtering.

WASTE PROCESSING

New, efficient technologies for destroying or vitrifying toxic and radioactive waste, using plasmas and high power microwaves, are entering the marketplace.

PLASMA ELECTRONICS

Plasma flat panel video displays such as moving maps, and plasma switches for electricity transmission, are part of a huge new industry using plasma electronics.

OTHER APPLICATIONS

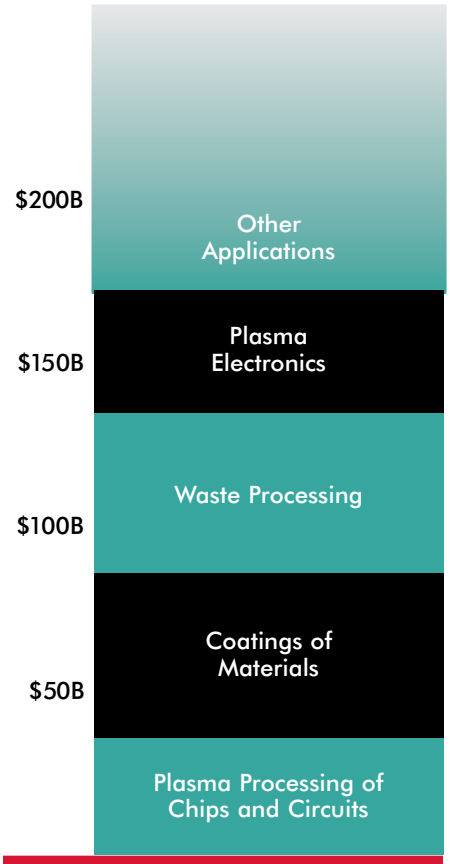
Plasma and fusion research is affecting many other areas, including biomedical applications, the development of new materials, the creation of new technologies, and contributions to many branches of science.

PLASMA

Often called "the fourth state of matter" (complementing solids, liquids and gases), plasma is a gas consisting of charged ions and electrons. Plasma can be controlled by electric and magnetic forces that permit individual beams of ions or electrons, or the plasma as a whole, to be accelerated and directed, allowing processes to be developed for a variety of specialized applications.

Plasmas can be produced over a wide range of temperatures (from near room temperature to the temperatures of the stars) and also over a wide range of densities (from above atmospheric down to near perfect vacuum). Plasmas are also produced from a wide range of elements (from all gases to almost all metals). This variety allows a vast range of possible applications, due to the thousands of different chemical combinations possible.

Fusion research requiring very high temperature and large experiments, and other applications accomplished at much lower temperature and with smaller equipment, depend on the same basic scientific principles and utilize similar technologies on differing scales.



Plasma processing technologies are beginning to make rapid inroads in these world markets valued at over $200 billion per year.

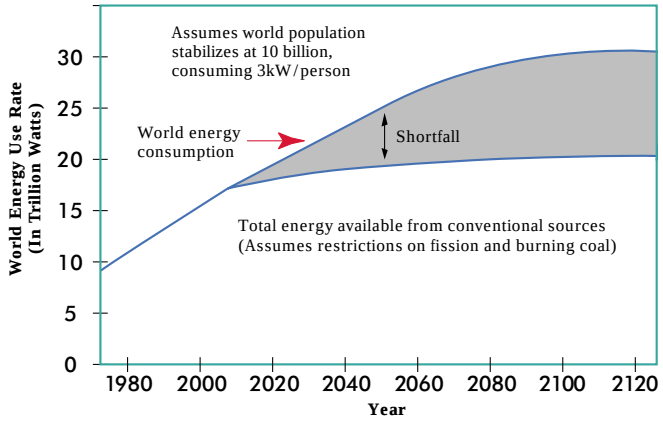
Energy Tomorrow

Energy is fundamental to the ability of society to function. It plays a critical role in our standard of living and in our security. It is entwined with world economic growth, environmental quality, and geopolitics.

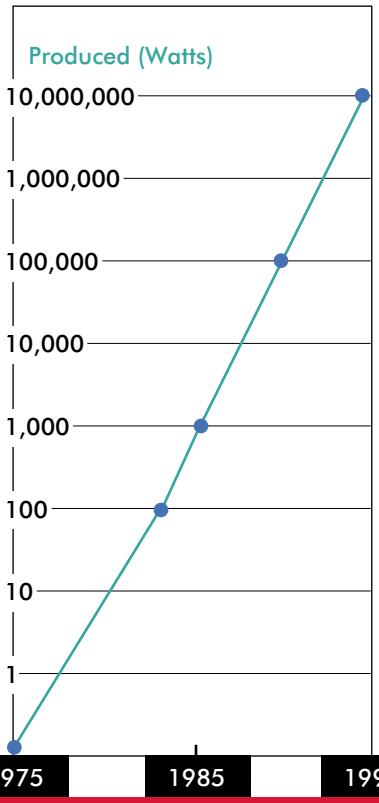
Technological advances emerging out of energy research and development will be critical to meeting future energy needs in an environmentally friendly manner, reducing stress on supply and consumption systems, diversifying risk, and avoiding or at least minimizing any future energy crisis.

Fusion promises many benefits, including:

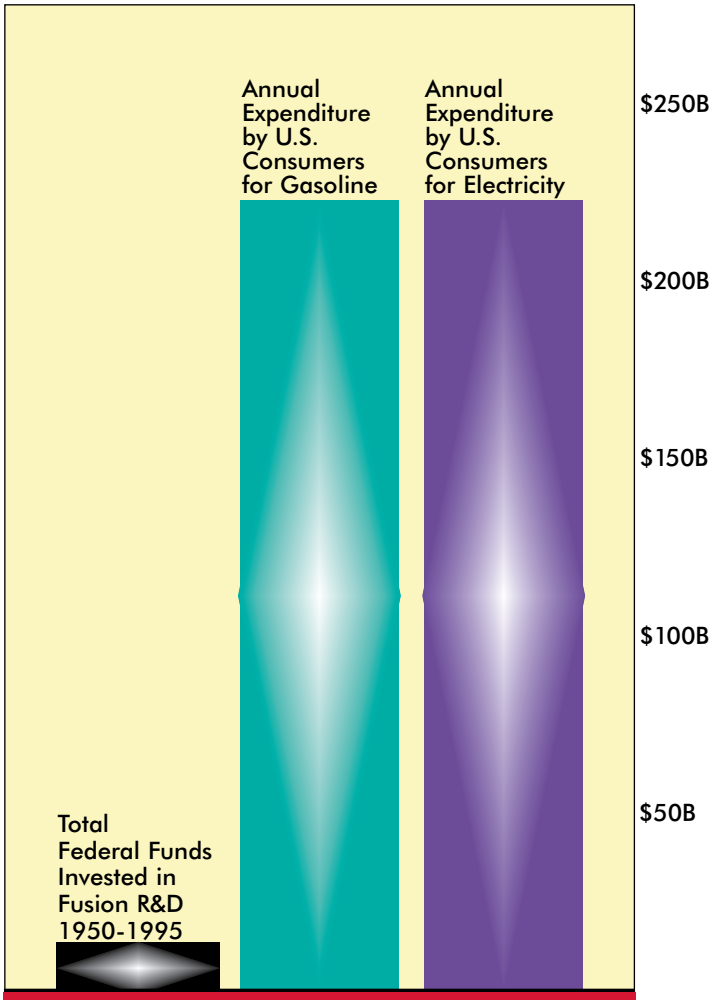
- **A universally available, essentially inexhaustible, efficient fuel resource**
- **An energy source with attractive safety and environmental characteristics, to meet growing global energy demand**
- **New technologies for a variety of applications**



World energy use may significantly exceed supply from conventional sources by the middle of the 21st Century.



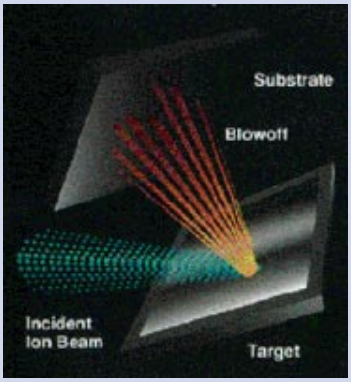
Progress in fusion has been steady and dramatic. Over the past 20 years the fusion power produced in experimental devices has increased over 100 million-fold, from 0.1 watt in 1975 to more than 10 million watts in 1995.



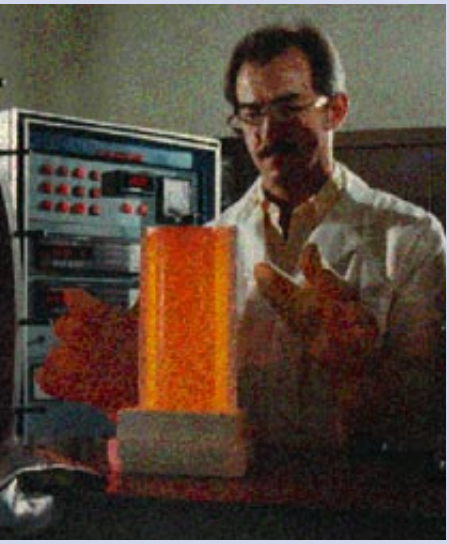
Fusion research is a modest investment by any standard.

COATINGS AND FILMS

Many commercial materials require coatings to reduce corrosion or to provide thermal protection. Plasma spray and intense ion beam technologies permit rapid deposition of uniform coatings on large, complex objects, such as turbine blades of aircraft engines. These technologies are also used for depositing diamond coatings on cutting tools and electronic circuits and for depositing polymer films on recording media. The estimated world market for coating technologies exceeds $50 billion a year.



Ion Beam Coating Technology: Los Alamos National Laboratory



Vitrified Ceramic: Oak Ridge National Laboratory

WASTE PROCESSING

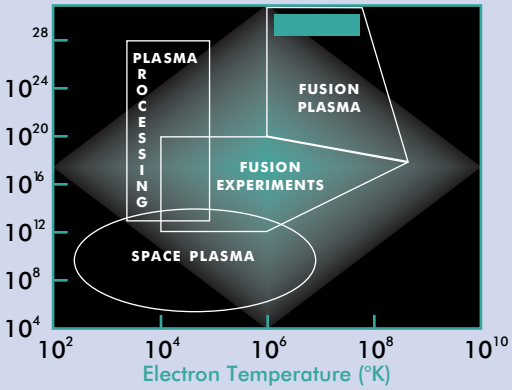
The disposal and/or destruction of toxic waste is a massive societal problem. Burning or chemical processing of such waste often results in the production of additional toxic material. Plasma can be used to melt solid waste and transform it into solid, non-leachable glass or ceramics. Plasma and beam technologies can be used to decompose toxic molecules in a gas. Mixed (radioactive and toxic) waste is being processed by plasma torches. Cryogenic and microwave technologies, developed for fusion research, are also being used for efficient cleaning of surfaces, e.g., removal of paint from aircraft. The estimated world market for toxic waste processing alone exceeds $50 billion a year.

PLASMA ELECTRONICS

Plasma electronics covers the range from plasma flat panel displays to arc-switching devices used in the power generation and transmission industry. Plasma flat panel displays permit compact, high quality full-color, full-motion videos, such as moving maps for transportation navigation. Arc-switching technologies improve efficiency and reduce maintenance costs in the electric power industry. The estimated world market for these applications exceeds $40 billion a year.

Full-color, full-motion video, plasma flat panel monitor: Photonics Imaging, Inc.

Plasma Regimes: Fusion Power Associates



CONTRIBUTIONS TO SCIENCE

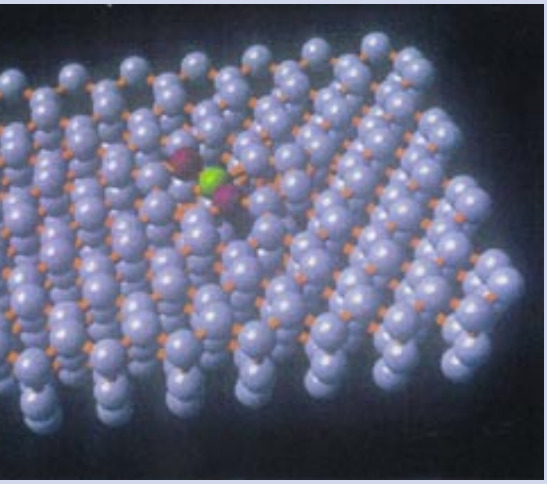
The development of plasma science has impacted many other areas of science, including astro, solar and magnetospheric physics; atomic physics; lasers; nonlinear dynamics and chaos; and numerical computation and modeling. Fusion researchers have pioneered in the field of supercomputer networking.

The fundamentals of plasma science, and the technologies required to study plasmas, underlie the many practical applications coming into use today, and eventually will lead to fusion as an energy source for tomorrow.

PLASMA PROCESSING OF CHIPS AND CIRCUITS

The speed of computer chips and integrated circuits is increased, and their size reduced, if plasma processes are used instead of chemical processing in their production. This has resulted in powerful computers becoming available to the average citizen. Advances in plasma technologies continue to reduce the size and cost of these products. The estimated world market for high performance chips and circuits exceeds $30 billion a year.

Pentium™ Chip Processing: Intel Corporation



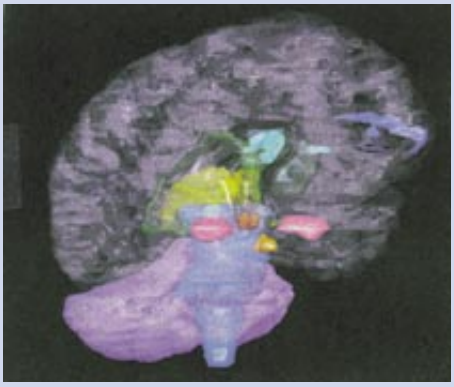
Synthetic Diamond: San Diego Supercomputer Center

NEW MATERIALS

Plasma and ion beams are used as the source of ions which, when implanted in the surface of materials, can result in new properties, such as increased hardness, decreased friction, increased smoothness, increased fatigue life, etc. Applications range from machine tools, ball bearings, and automotive components, to implants and prosthetics. Plasma and microwave technologies are also used to greatly reduce the time required to process high performance ceramics, itself a $5 billion a year industry. Plasmas alter the normal pathways through which chemical systems evolve from one stable state to another, thus providing the potential to produce materials with properties that are not attainable by any other means. Materials, including carbon fiber composites, that are more resistant to thermal shock have been developed due to the requirements of high temperature plasma experiments.

BIOMEDICAL APPLICATIONS

A wide range of medical applications can trace their origins to plasma and fusion research, from magnets used in magnetic resonance imaging (MRI) to tomography and interferometric imaging first developed to diagnose plasma experiments. Laser surgery and tissue welding, and their associated computerized controls and interpretive diagnostics, also have connections to fusion research.



Medical Imaging: San Diego Supercomputer Center

Plasma light bulb: Fusion Lighting, Inc.

NEW TECHNOLOGIES

Fusion and plasma research has opened up a wide range of new technologies and applications. High efficiency ultraviolet and visible light sources, emitted from plasmas, are in use for rapid drying of special inks, coatings, and adhesives, as well as for lighting large areas with reduced energy consumption. For example, the visible light from a golf-ball-sized plasma produced by microwaves, yields as much light as 250 one-hundred watt bulbs at a fraction of the corresponding energy consumption.

Fusion scientists developing high speed digitizers for diagnosing laser-produced plasma, have applied the technology to a new radar device, with a cost of about $20. These devices, which can fit in the palm of the hand, have many applications such as low cost surveillance systems and sensors.

"Every time you look up in the sky, every one of those points of light is a reminder that fusion power is an everyday reality throughout the galaxy"

—Carl Sagan
Cornell University

"Perhaps the least obvious contribution of the fusion energy program has been its impact on the development of computer networking, which was partly driven by the need of fusion researchers for access to supercomputers to solve complex, non-linear problems in plasma turbulence"

—Secretary of Energy Advisory Board Task Force on Energy R&D, 1995

"Plasma processing is a principal manufacturing technology for integrated circuits in computers, communications equipment, and consumer electronics products. This technology also reduces toxic wastes from microelectronic-circuit manufacturing."

—President's Council of Advisors on Science and Technology, July 1995

"Plasma processing is a technology that is of vital importance to several of the largest industries in the world, including the electronics, aerospace, automotive, steel, biomedical and toxic waste management industries."

—"Plasma Processing of Materials" 1991 Report of the National Research Council

"Plasma science is fundamental to the prediction of 'space weather' in the ionosphere and magnetosphere and is essential for designing global communications systems and for assuring longevity in satellites and spacecraft."

—Neil Armstrong
Astronaut

"I remain dedicated to the concept of fusion power, as a citizen, and I wish I was in a position to do more about it."

—Ansel Adams
Photographer
July 18, 1983

"The science of plasma physics, and the technologies related to it, for which nearly all of the funding comes from fusion energy R&D budgets, has been prolific in the production of insights and techniques with wide applications in other fields of science and industry."

—John P. Holdren
Professor of Energy
University of California, Berkeley

"To put some five million transistors on a Pentium™ chip, the individual elements have to be below 0.5 microns in size and moving toward 0.25 microns. Such resolution cannot be achieved without a plasma."

—Prof. Francis F. Chen
UCLA, June 1995

FOR FURTHER INFORMATION: OFFICE OF FUSION ENERGY • DEPARTMENT OF ENERGY
WASHINGTON, DC 20585 • WORLD WIDE WEB ADDRESS: http://wwwofe.er.doe.gov

Photo: Plasma Etching of Semiconductor Chip: University of Wisconsin Engineering Research Center for Plasma-Aided Manufacturing